OOM_questions_CBPs_with_HAT

December 19, 2016

0.1 For CBPs

- Find updated info on status of HATS light curves. How long are the baselines, at what precision?
- How many EBs will they likely have? -> based, e.g., on Kepler EB statistics. (Get & read the EB working group's papers)
- What was the Kepler EB->CBP rate? (e.g. review Haghihipour's talk) Would *ANY* of these have been detected by a survey like HATS?
- How many will be at sufficient precision for single-transit detections?
- How many will be at sufficient precision for phase-folded detections?
- What would necessary properties of the CBP population *BE* in order to expect *any* CBPs in the HAT data?
- Should this be sufficient to detect CBPs based on Kepler data? (what was the thing I mentioned in my application?)

Getting into the data weeds: * What are common CBP search methods? Uncommon ones? * For instance… what would the necessary conditions be just on *eclipse timing* to constitute a bonafide CBP detection? (the literature on this is probably more scattered, & more oriented on heuristics to numerical N body orbit intergration)

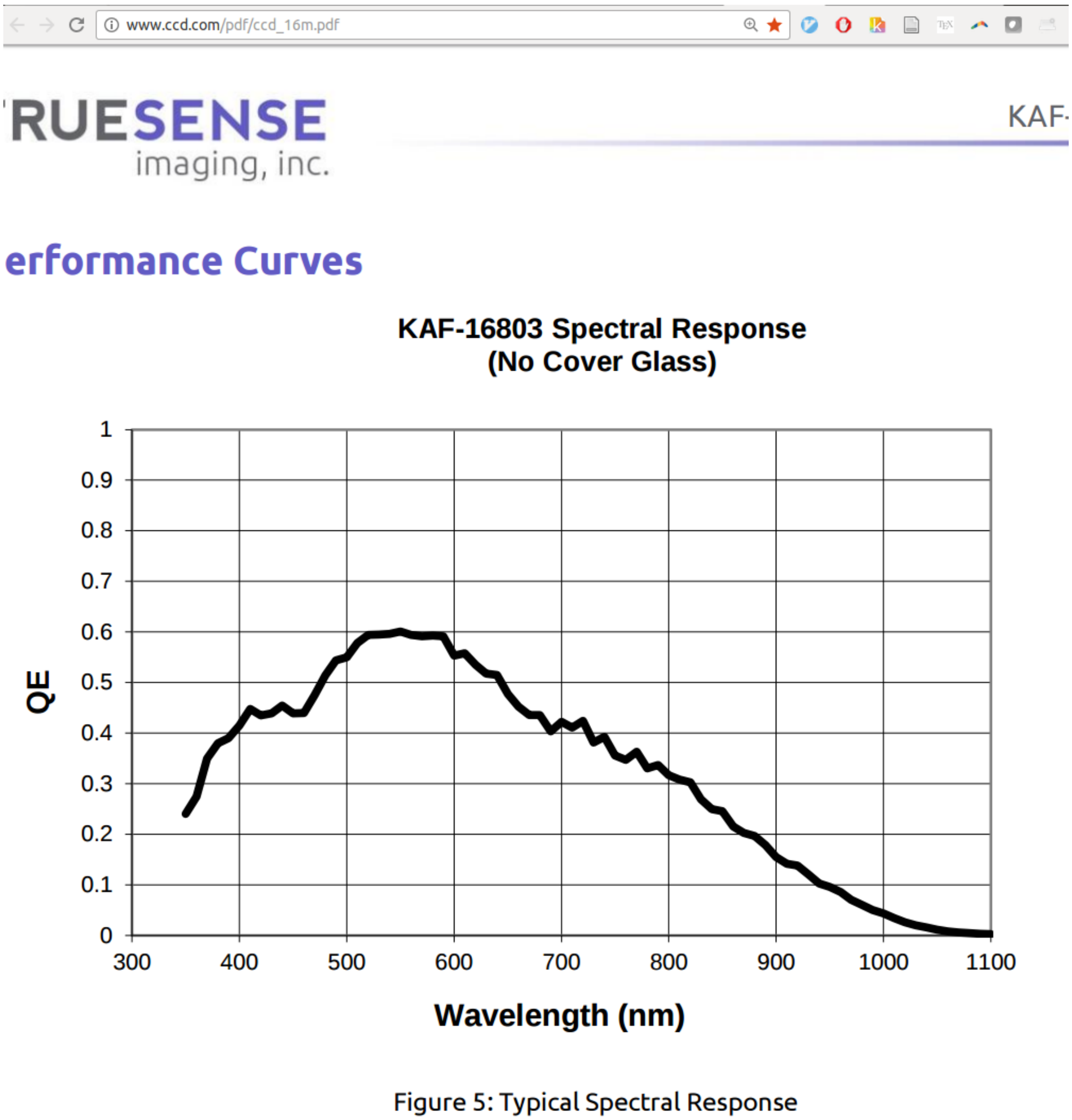
0.2 For the M dwarf search

HAT bandpass:

```
In [1]: import IPython.display as ipd
```

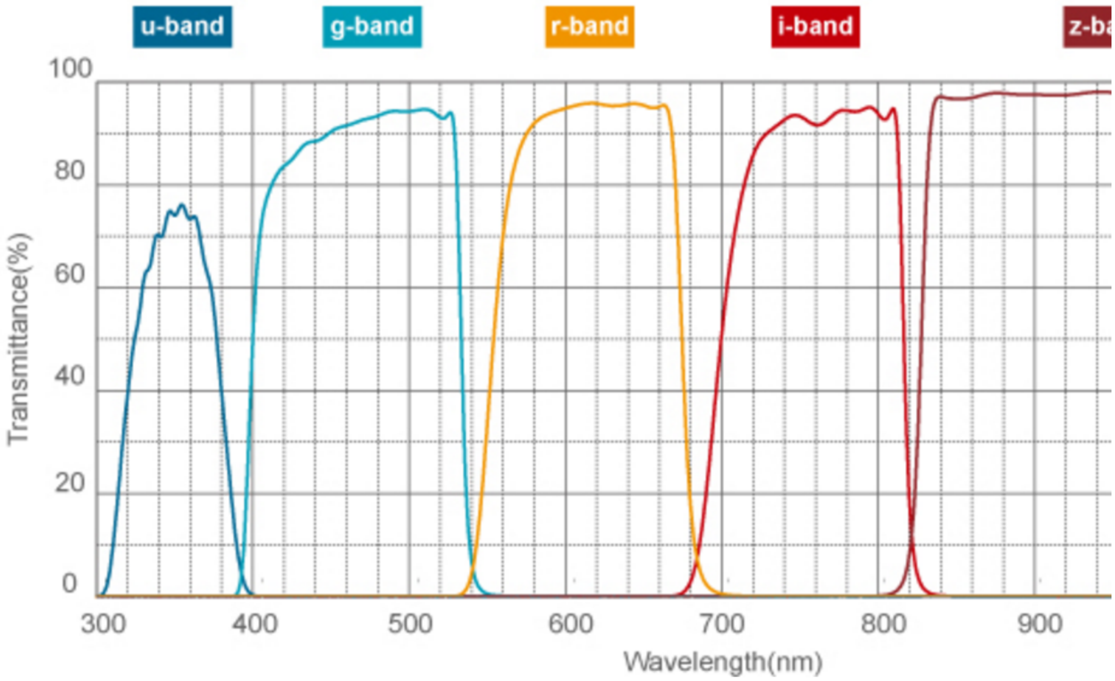
```
In [2]: ipd.Image('what_is_HAT_bandpass.png')
```

```
Out[2]:
```




```
In [3]: ipd.Image('r_band_sloan_filters.png')
```

Out[3]:



So M dwarf sensitivity is *not* what they're specializing in.
16/09/07

0.3 Find updated info on status of HATS light curves. How long are the baselines, at what precision?

Over first 2 years: 1,060,000 4k*4k 4 minute images. And ~18 8.2x8.2 square degree fields have >10,000 observations per field.

```
In [4]: print('Typical HAT baseline is: {:.1f} days '.format(round(1e4*4 / (60*24),
```

```
Typical HAT baseline is: 27.8 days
```

And the sensitivity is:

```
In [5]: from IPython.display import Image
        Image('HAT_precision.png')
```

```
Out[5]:
```

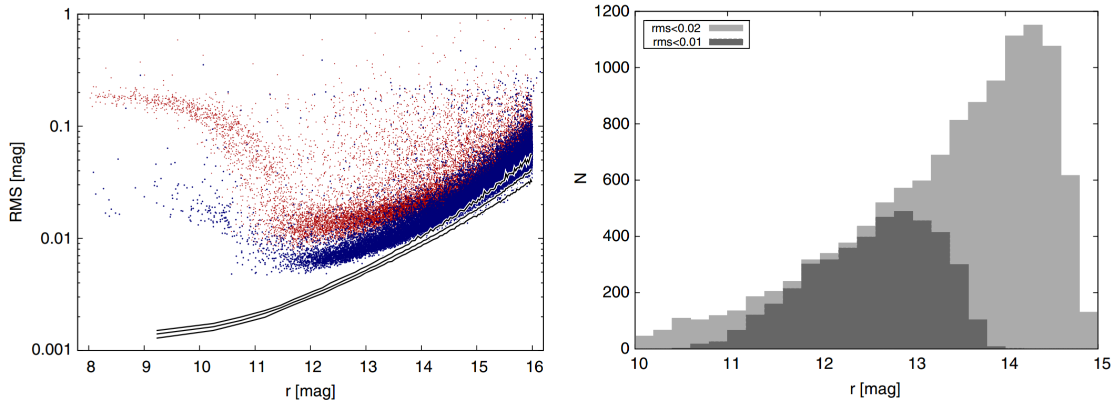


FIG. 8.—The *left panel* shows the standard deviation of light curves around the median as a function of Sloan r magnitude. The light (*red*) points refer to the fitted magnitudes (`fitmag` in § 5), and dark (*blue*) points refer to the TFA corrected `tfamag` values. Each point represents a light curve. The standard deviation has been corrected for the effect of using a number of template stars in the TFA fitting procedure. We use the optimal aperture (among three discrete choices) for each light curve, which choice is a function of the average magnitude of the star. We overplot the expected rms for each light curve, taking into account the expected photometric error for each observation within the light curve (calculated from the actual flux and sky background) and with scintillation noise (Dravins et al. 1998) added in quadrature to the noise term. We show the 10% (*lowest line*), 50% (*middle line*) and 90% percentile, as a function of magnitude, from the distribution of the expected rms. The *right panel* shows the histogram of the number of stars in this particular (sparse) field with TFA rms smaller than 0.01 as a function of r band magnitude (*dark gray*) and similar data for TFA rms smaller than 0.02 (*light gray*). See the electronic edition of the *PASP* for a color version of this figure.

We are told the right figure is a sparse field. Bin widths are 0.2mag, so there are around

```
In [6]: int(0.5 * 1000 * (14.5-10.8) / 0.2 )

Out[6]: 9249

In [7]: 0.5*500*(13-10.8)/0.2

Out[7]: 2749.9999999999986

In [8]: 4/9.

Out[8]: 0.4444444444444444
```

stars in it. This means that perhaps a less-sparse field will have around 20k stars in it. And sparse fields have around 10k stars in them.

This means that after 2 years, they have at minimum

```
In [9]: print('{:1g}'.format(18 * 1e4))

180000
```

light curves, and more likely closer to

```
In [10]: print('{:g}'.format(18 * 2e4))

360000
```

stars with light curves at less than 2% precision (20 mmag), at around 30 days (to more) of coverage. Note this was at the end of 2012, after 2 years of observing. In *discussion*, Gaspar claimed that they have 4 million light curves at <2% precision, although it may be the case that a good fraction of them have $t_{\rm obs} < 30$ day.

0.4 How many EBs will they likely have? based, e.g., on Kepler EB statistics. (Get & read the EB working group's papers)

Kepler's EB team found around 10 CBPs from 2000 EBs (give or take, perhaps more like 3000 EBs with modern updates).

In [11]:
```
import xml.etree.ElementTree as ET, urllib.request, gzip, io
url = "https://github.com/OpenExoplanetCatalogue/oec_gzip/raw/master/syste
oec = ET.parse(gzip.GzipFile(fileobj=io.BytesIO(urllib.request.urlopen(url

# Output mass and radius of all planets
MR_list = []
for planet in oec.findall(".//planet"):
    MR_list.append([planet.findtext("mass"), planet.findtext("radius")])

# Find all circumbinary planets
CBP_names = []
for planet in oec.findall(".//binary/planet"):
    CBP_names.append(planet.findtext("name"))

# Output distance to planetary system (in pc, if known) and number of plan
distances = []
for system in oec.findall(".//system"):
    distances.append([system.findtext("distance"), len(system.findall(".//
```

In [12]:
```
CBP_names
```

Out[12]:
```
['2M 1938+4603 b',
 'DP Leo b',
 'FL Lyr b',
 'FW Tau b',
 'HU Aqr (AB) b',
 'HU Aqr (AB) c',
 'HU Aqr (AB) d',
 'HW Vir (AB) b',
 'Kepler-16 (AB) b',
 'Kepler-34 (AB) b',
 'Kepler-35 (AB) b',
 'Kepler-38 (AB) b',
 'Kepler-413 b',
 'Kepler-47 (AB) b',
 'Kepler-47 (AB) c',
 'KIC 9632895 b',
 'KOI-2939 b',
 'NN Ser (AB) c',
 'NN Ser (AB) d',
 'NSVS 14256825 c',
 'NSVS 14256825 d',
 'NY Virginis (AB) b',
```

```
'PH-1 A(ab) b',
'PSR B1620-26 b',
'Ross 458 C',
'ROXs 42 B b',
'RR Cae (AB) b',
'SR 12 C']
```

Compare these names with what I know from papers:

```
In [13]: Image('all_kepler_transiting_CBPs.png') # thanks to Martin, Fabrycky 2016
```

Out[13]:

Table 1. The *Kepler* transiting circumbinary planets

Name	M_1 [$M_\odot$]	M_2 [$M_\odot$]	$a_{\rm in}$ [AU]	$P_{\rm in}$ [d]	$e_{\rm in}$	$R_{\rm p}$ [$R_\oplus$]	$a_{\rm p}$ [AU]	$P_{\rm p}$ [d]	$e_{\rm p}$	$\Delta I_{\rm p,in}$ [deg]	$a_{\rm crit}$ [AU]	Reference
16	0.69	0.20	0.22	40.1	0.16	8.27	0.71	228.8	0.01	0.31	0.64	Doyle et al. (2011)
34	1.05	1.02	0.23	28.0	0.52	8.38	1.09	288.8	0.18	1.86	0.84	Welsh et al. (2012)
35	0.89	0.81	0.18	20.7	0.14	7.99	0.60	131.4	0.04	1.07	0.50	Welsh et al. (2012)
38	0.95	0.26	0.15	18.8	0.10	4.35	0.47	106.0	0.07	0.18	0.39	Orosz et al. (2012a)
47b	1.04	0.36	0.08	7.4	0.02	2.98	0.30	49.5	0.04	0.27	0.20	Orosz et al. (2012b)
47d	1.04	0.36	0.08	7.4	0.02	—	0.72	187.3	—	—	0.20	Orosz (in prep)
47c	1.04	0.36	0.08	7.4	0.02	4.61	0.99	303.1	<0.41	1.16	0.20	Orosz et al. (2012b)
PH-1/64	1.50	0.40	0.18	20.0	0.21	6.18	0.65	138.5	0.07	2.81	0.54	Schwamb et al. (2013); Kostov et al. (2013)
413	0.82	0.54	0.10	10.1	0.04	4.34	0.36	66.3	0.12	4.02	0.26	Kostov et al. (2014)
3151	0.93	0.19	0.18	27.3	0.05	6.17	0.79	240.5	0.04	2.90	0.44	Welsh et al. (2014b)

```
In [14]: import pandas as pd

In [15]: m_star, ix = [], -1
         for binary in oec.findall('.//binary'):
             for planet in binary.findall('.//planet'):
                 m_star.append([binary.findtext('name'), planet.findtext('name'), p
                 ix += 1
             for star in binary.findall('.//star'):
                 m_star[ix].append(star.findtext('name'))
                 m_star[ix].append(star.findtext('mass'))

In [16]: CBPs = {'name':[], 'period_planet_[day]': [],
                 'is_transiting': [], 'discovery_method': []}
         for planet in oec.findall('.//binary/planet'):
             CBPs['name'].append(planet.findtext('name'))
             CBPs['period_planet_[day]'].append(planet.findtext('period'))
             CBPs['is_transiting'].append(planet.findtext('istransiting'))
             CBPs['discovery_method'].append(planet.findtext('discoverymethod'))



         CBPs = pd.DataFrame(CBPs, index=CBPs['name'])
```

```
In [17]: CBPs

Out[17]:                    discovery_method is_transiting                name  \
         2M 1938+4603 b               timing          None      2M 1938+4603 b
         DP Leo b                     timing             1            DP Leo b
         FL Lyr b                     timing          None            FL Lyr b
         FW Tau b                    imaging          None            FW Tau b
         HU Aqr (AB) b                timing          None       HU Aqr (AB) b
         HU Aqr (AB) c                timing          None       HU Aqr (AB) c
         HU Aqr (AB) d                timing          None       HU Aqr (AB) d
         HW Vir (AB) b                timing          None       HW Vir (AB) b
         Kepler-16 (AB) b            transit             1    Kepler-16 (AB) b
         Kepler-34 (AB) b            transit             1    Kepler-34 (AB) b
         Kepler-35 (AB) b            transit             1    Kepler-35 (AB) b
         Kepler-38 (AB) b            transit             1    Kepler-38 (AB) b
         Kepler-413 b                transit             1        Kepler-413 b
         Kepler-47 (AB) b            transit             1    Kepler-47 (AB) b
         Kepler-47 (AB) c            transit             1    Kepler-47 (AB) c
         KIC 9632895 b               transit             1       KIC 9632895 b
         KOI-2939 b                  transit             1          KOI-2939 b
         NN Ser (AB) c                timing          None       NN Ser (AB) c
         NN Ser (AB) d                timing          None       NN Ser (AB) d
         NSVS 14256825 c              timing          None     NSVS 14256825 c
         NSVS 14256825 d              timing          None     NSVS 14256825 d
         NY Virginis (AB) b           timing          None  NY Virginis (AB) b
         PH-1 A(ab) b                transit             1        PH-1 A(ab) b
         PSR B1620-26 b               timing          None      PSR B1620-26 b
         Ross 458 C                  imaging          None          Ross 458 C
         ROXs 42 B b                 imaging          None         ROXs 42 B b
         RR Cae (AB) b                timing          None       RR Cae (AB) b
         SR 12 C                     imaging          None             SR 12 C

                           period_planet_[day]
         2M 1938+4603 b                    416
         DP Leo b                        10230
         FL Lyr b
         FW Tau b                         None
         HU Aqr (AB) b                    None
         HU Aqr (AB) c                    None
         HU Aqr (AB) d                    None
         HW Vir (AB) b                    4640
         Kepler-16 (AB) b              228.776
         Kepler-34 (AB) b              288.822
         Kepler-35 (AB) b              131.458
         Kepler-38 (AB) b              105.595
         Kepler-413 b                   66.262
         Kepler-47 (AB) b               49.514
         Kepler-47 (AB) c              303.158
```

```
KIC 9632895 b                    240.503
KOI-2939 b                      1107.5923
NN Ser (AB) c                   5654.6797
NN Ser (AB) d                     2793.0
NSVS 14256825 c                     1276
NSVS 14256825 d                     2506
NY Virginis (AB) b                  2900
PH-1 A(ab) b                     138.506
PSR B1620-26 b                     24837
Ross 458 C                          None
ROXs 42 B b                         None
RR Cae (AB) b                       4350
SR 12 C                             None
```

```
In [18]: foo = oec.findall(".//binary/planet")[0]
```

```
In [19]: bar = foo.getiterator()
```

```
In [ ]:
```

- What was the Kepler EB->CBP rate? (e.g. review Haghihipour's talk) Would *ANY* of these have been detected by a survey like HATS?
- How many will be at sufficient precision for single-transit detections?
- How many will be at sufficient precision for phase-folded detections?
- What would necessary properties of the CBP population *BE* in order to expect *any* CBPs in the HAT data?
- Should this be sufficient to detect CBPs based on Kepler data? (what was the thing I mentioned in my application?)

```
In [ ]:
```